Decay rate asymmetry for $B \to X_s\gamma$ in SUSY model

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Abstract.

  We discuss a rate asymmetry for the radiative B-meson decay $B \to X_s\gamma$ within the framework of the supersymmetric standard model based on $N = 1$ supergravity. This model contains new sources of CP violation. In spite of severe experimental constraints on the electric dipole moment of the neutron, a new CP-violating phase may not be suppressed, leading to a sizable enhancement of the decay rate asymmetry. The magnitude of the asymmetry is predicted to be larger than that by the standard model in wide parameter regions where the branching ratio is consistent with its experimental bounds. A possible maximal magnitude is about 0.1, which will be well accessible at B factories.

The radiative B-meson decay $B \to X_s \gamma$ is sensitive to new physics around the electroweak scale. Owing to a large mass of the b quark, its inclusive mode is well described by the free b-quark decays $b \to s\gamma$ and $b \to s\gamma g$, to which new interactions may give sizable contributions. In particular, the supersymmetric standard model (SSM) has various new sources for the contributions [1]. Although the experimental results for the branching ratio [2, 3] is consistent with the standard model (SM), a decay rate asymmetry

$$\mathcal{A}_{CP} = \frac{\Gamma(\overline{B} \to X_s \gamma) - \Gamma(B \to X_{\bar{s}} \gamma)}{\Gamma(\overline{B} \to X_s \gamma) + \Gamma(B \to X_{\bar{s}} \gamma)}$$

could nontrivially differ in the SSM [4] from the SM prediction, which we discuss in this report.

We assume the SSM based on $N = 1$ supergravity and grand unification. At the electroweak scale, the squarks of interaction eigenstates are mixed in generation space. The squarks, as well as the quarks, mediate the processes of flavor-changing neutral current (FCNC). The generation mixings among the up-type squarks are approximately lifted by using the same matrices that diagonalize the mass matrix of the up-type quarks. As a result, the generation mixings in the interactions between up-type squarks and down-type quarks are described by the Cabibbo-Kobayashi-Maskawa matrix for the quarks.

The squark mass-squared matrices and the chargino mass matrix have new sources of CP violation. For physical complex parameters, without loss of generality, we can take the dimensionless coefficient A and the Higgsino mass parameter μ, which are expressed as $A = |A| \exp(i\alpha)$ and $\mu = |\mu| \exp(i\theta)$, respectively. We neglect the differences of the dimensionless coefficients among flavors. The CP-violating phase θ is severely constrained by the experimental bounds on the electric dipole moment (EDM) of the neutron [5]. If θ is of order unity, the squarks are not allowed to have masses smaller than 1 TeV. On the other hand, for a sufficiently small magnitude of θ and relatively large masses for gauginos, the squarks can be of order 100 GeV with another CP-violating phase α being unsuppressed [6]. In this parameter region the SSM may induce sizable CP violation without causing discrepancies for the EDM.

The effective Hamiltonian for the decays $b \to s\gamma$ and $b \to s\gamma g$ is written generally by

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{j=1}^{8} C_j(\mu) O_j(\mu),$$

$$O_2 = \overline{s_L} \gamma_\mu c_L \overline{c_L} \gamma^\mu b_L, \quad O_7 = \frac{e}{16\pi^2} m_b \overline{s_L} \sigma^{\mu\nu} b_R F_{\mu\nu}, \quad O_8 = \frac{g_s}{16\pi^2} m_b \overline{s_L} \sigma^{\mu\nu} T^a b_R G_{\mu\nu}^a.$$

Here $C_j(\mu)$ denotes a Wilson coefficient evaluated at the scale μ, and $F_{\mu\nu}$ and $G_{\mu\nu}$ respectively represent the electromagnetic and strong field strength tensors, T^a being the generator of SU(3). The contributions from the operators other than O_2, O_7, and O_8 are negligible.

The Wilson coefficients C_7 and C_8 of the electroweak scale receive contributions at the one-loop level. Sizable new contributions come from the diagrams in which

the charginos ω or the charged Higgs bosons $H^{\pm}$ are exchanged together with the up-type squarks or the up-type quarks, respectively. The coefficients are expressed at the leading order as $C_2(M_W) = 1$ and $C_j(M_W) = C_j^W(M_W) + C_j^{H^{\pm}}(M_W) + C_j^{\omega}(M_W)$ ($j = 7, 8$), where C_j^W, $C_j^{H^{\pm}}$, and C_j^{ω} stand respectively for the contributions from W bosons, charged Higgs bosons, and charginos. In our scheme for the SSM, the one-loop diagrams mediated by the gluinos or the neutralinos with the down-type squarks cause only small effects on both FCNC and CP violation.

The contributions $C_7^{\omega}(M_W)$ and $C_8^{\omega}(M_W)$ have complex values, owing to the physical complex phase intrinsic in the SSM. Therefore, CP invariance is violated in the decay $B \to X_s \gamma$. Another important effect by the SSM is that $C_7^{\omega}(M_W)$ and $C_8^{\omega}(M_W)$ can be added to $C_7^W(M_W)$ and $C_8^W(M_W)$ both constructively and destructively depending on the parameter values. On the other hand, $C_7^{H^{\pm}}(M_W)$ and $C_8^{H^{\pm}}(M_W)$ are added constructively. These effects make it possible to have a large magnitude for the decay rate asymmetry while keeping the branching ratio comparable with the SM value.

The rate asymmetry in the decay $B \to X_s \gamma$ is attributed to decay rate asymmetries for $b \to s\gamma$ and $b \to s\gamma g$, which are induced by the interferences between the tree level processes and the one-loop level processes with absorptive parts. The asymmetry $\mathcal{A}_{CP}$ is expressed in terms of the Wilson coefficients at the b-quark mass scale [7, 8], which are obtained by solving the renormalization-group equations.

The parameter values of the SSM are constrained by the measured branching ratio of $B \to X_s \gamma$, as well as direct searches for supersymmetric particles. We calculate the decay width of $B \to X_s \gamma$ by using the matrix elements and anomalous dimensions at the next-to-leading order (NLO). However, NLO corrections for the matching conditions of C_7^{ω} and C_8^{ω} at the electroweak scale have not yet obtained in general form. Therefore, the NLO matching conditions are taken into account only for the W-boson contributions.

The decay rate asymmetry for $B \to X_s \gamma$ is analyzed numerically together with its branching ratio. Taking into account experimental constraints on the EDM of the neutron, we assume $\alpha \sim \pi/4$ and $\theta \sim 0$ for the CP-violating phases, and $\widetilde{m}_2 \gtrsim 500$ GeV for the SU(2) gaugino mass. The mass parameters for the charged Higgs boson and the Higgsino are taken for $M_{H^{\pm}} \sim 100$ GeV and $\mu \sim 100$ GeV, respectively. For simplicity, we assume that the soft supersymmetry-breaking masses of the t squarks at the electroweak scale are given as $\widetilde{m}^2 - cm_t^2$ and $\widetilde{m}^2 - 2cm_t^2$ respectively for $\tilde{t}_L$ and $\tilde{t}_R$. A dimensionless constant c is introduced to parametrize radiative corrections to the squark masses though Yukawa interactions, with $c = 0.1 - 1$. We take $\widetilde{m}/|A|m_{3/2} = 0.5 - 2$ and $|A|m_{3/2} \lesssim 1$ TeV, where $m_{3/2}$ denotes the gravitino mass. The ratio of the vacuum expectation values is considered to be $\tan\beta = 2 - 35$. The energy cutoff parameter δ for the photon is taken to be 0.99, though the decay rate asymmetry is not changed so much by the choice of its value.

For $\tan\beta = 10$, the branching ratio lies within the experimental bounds in the mass range 100 GeV $\lesssim \widetilde{M}_{t1} \lesssim 400$ GeV for the lighter t-squark, where the asymmetry has a value $0.02 \lesssim |\mathcal{A}_{CP}| \lesssim 0.07$. The magnitude of the asymmetry becomes maximum at $\widetilde{M}_{t1} \simeq 200$ GeV, which gives roughly a minimum value of the branching ratio. The

maximal value of the asymmetry does not depend significantly on $\tan\beta$. The peaks of the asymmetry and the branching ratio are roughly at the same value of $\widetilde{M}_{t1}$, which increases with $\tan\beta$.

Assuming that the CP-violating phase α is not suppressed and the charged Higgs boson mass is of order 100 GeV, the magnitude of the asymmetry is larger than 0.01 in wide parameter regions consistent with the experiments on the branching ratio. The SM prediction is smaller than 0.01. If the charged Higgs boson is not heavy, the sum of the contributions of W and $H^{\pm}$ alone makes the decay width too large. Therefore, in the SSM parameter region allowed by the branching ratio, the chargino contribution has to be comparable with the contributions of W and $H^{\pm}$. Then, a large CP asymmetry is induced. If the charged Higgs boson is sufficiently heavy, its contribution to the decay width is negligible. Still, there are parameter regions where the asymmetry is larger than 0.01 without conflicting with the measured branching ratio.

We have discussed the decay rate asymmetry for the radiative B-meson decay $B \to X_s\gamma$ in the SSM based on $N = 1$ supergravity and grand unification. This model predicts various new contributions to the decay, among which the chargino and the charged Higgs boson loop diagrams yield sizable effects. Assuming an unsuppressed CP-violating phase intrinsic in the SSM, the asymmetry can have a large value, maximally of order 0.1, which is not expected by the SM. Such a magnitude of the asymmetry may well be detectable at B factories. In particular, the obtained experimental results that the branching ratio is consistent with the SM would imply a large asymmetry. The decay rate asymmetry of $B \to X_s\gamma$ seems worth measuring in the present or near-future experiments.

References

[1] N. Oshimo, 1993 *Nucl. Phys.* **B404**, 20 .
[2] M.S. Alam *et al* (CLEO Collaboration), 1995 *Phys. Rev. Lett.* **74**, 2885 ;
    T. Coan (CLEO Collaboration), Talk given at the ICHEP2000.
[3] R. Barate *et al* (ALEPH Collaboration), 1998 *Phys. Lett.* **B429**, 169 .
[4] M. Aoki, G.C. Cho, and N. Oshimo, 1999 *Phys. Rev.* **D60**, 035004 ; 1999 *Nucl. Phys.* **B554**, 50 .
[5] Y. Kizukuri and N. Oshimo, 1992 *Phys. Rev.* **D45**, 1806 ; 1992 *Phys. Rev.* **D46**, 3025 .
[6] M. Aoki and N. Oshimo, 1998 *Nucl. Phys.* **B531**, 49 .
[7] A.L. Kagan and M. Neubert, 1998 *Phys. Rev.* **D58**, 094012 .
[8] N. Pott, 1996 *Phys. Rev.* **D54**, 938 ;
    C. Greub, T. Hurth, and D. Wyler, 1996 *Phys. Lett.* **B380**, 385 ; 1996 *Phys. Rev.* **D54**, 3350 .